CEMENT
AND
CEMENT MANUFACTURE

PUBLISHED 20TH OF EACH MONTH. PRICE 1/- A COPY. ANNUAL SUBSCRIPTION 12s. POST FREE.

PUBLISHED BY
CONCRETE PUBLICATIONS LIMITED,
20, DARTMOUTH STREET, LONDON, S.W.1.
TELEPHONE: WHITEHALL 4581.
TELEGRAPHIC ADDRESS:
CONCRETIUS, PARL, LONDON.

PUBLISHERS OF
"CONCRETE & CONSTRUCTIONAL ENGINEERING"
"CONCRETE BUILDING & CONCRETE PRODUCTS"
"CEMENT & CEMENT MANUFACTURE"
"THE CONCRETE YEAR BOOK"
"CONCRETE SERIES" BOOKS, ETC.

VOLUME 9. NUMBER 2. FEBRUARY 1936

Heat Transmission in Rotary Kilns.—Part XII.

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(*Concluded.*)

Appendix I.

Application of Schmidt's Method to the Heating of Cement Material Cubes.

(289) A rectangular block of material of length AB is indicated in *Fig.* 55. Suppose the face AD receives heat and the remaining five faces are insulated from surrounding temperatures. It is required to find the temperature at any point in the block after any period of heating. The block is divided into any convenient number of parallel plates, and the temperature at each dividing plane and at each end surface is determined at the end of a number of equal intervals of time.

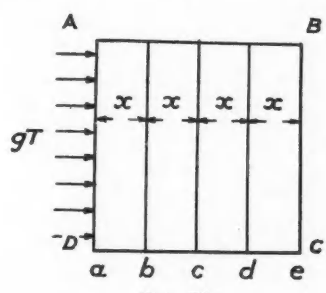

Fig. 55.

(290) The notation used is as follows :

gT = gas or flame temperature in deg. Fah. to which the face AD is exposed.

H = heat transfer in B.T.U. per square foot per hour per deg. Fah.

x = width of elementary plate in feet.

t = length of elementary heating period in hours.

W, ϕ, and K are defined in Table XL.

There is a definite relation between t and x which is

$$t = \frac{x^2 W\phi}{2K} \quad \ldots \quad (14)$$

The method of tabulation used is shown in Table XLIII.

TABLE XLIII.

Line No.	Period No.	Surface and division temperatures				
		(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
(1)	0	L	M	N	O	P
(2)	1	aT	R	S	V	eT

(291) In Table XLIII the temperature of the face AD at the end of each period is entered in Col. (*a*) and the temperature of the face BC in Col. (*e*). The temperatures at the dividing planes are entered in Cols. (*b*), (*c*), and (*d*). These letters correspond to those shown in *Fig.* 55.

Referring to line (1), the initial temperatures denoted by L, M, N, O, and P are supposed to be known. At the end of the first period, see line (2), the intermediate temperatures R, S, and V are obtained by Schmidt's rule from temperatures to the left and right in line (1) as follows:

$$R = \frac{L + N}{2}, \quad S = \frac{M + O}{2}, \quad V = \frac{N + P}{2}$$

(292) It remains to find the end temperatures aT and eT. The published information on this point is meagre, and after investigation the writer suggests the following formulæ. For the temperature of the surface AD at the end of each period

$$aT = \frac{(2 \times gT \times Hx) + L(K - Hx) + (M + R)K}{3K - Hx} \quad \ldots \quad (15)$$

L, M, and R are temperatures adjacent to aT, which are known.

For the temperature of the surface BC at the end of each period,

$$eT = \frac{1}{3}(V + O + P) \quad \ldots \quad (16)$$

The subject is further illustrated by the example given in Appendix II, para. (297).

The quantity of heat supplied to the block during any period depends on the average temperature of the face AD during that period, and this can be found from Col. (*a*) in Table XLIII. It is desirable to check the heat supplied against the heat stored in the block, as shown by the rise of its average temperature.

If the rate of heat supply suddenly changes, formula (15) will give a better result if the width of each elementary plate is relatively small.

(293) DETERMINATION OF LINING STORAGE FACTOR.—Schmidt's method may be used to determine the storage factor for the kiln lining in each stage. The fluctuation of the lining surface temperature and the penetration are obtained by the same process. The starting point is conveniently the surface temperature of a lining block as it passes from under the material. This is assumed in the first instance and, if the assumption is correct, the block surface temperature after completing one revolution will return to its original value.

The value of x may be 0.06 in., and the number of elementary plates about six. Formula (15) is used without change of sign both when the block is taking in heat and giving out heat, but the values of gT and H are different. For further information see Part III, paras. (54) to (59), and *Figs.* 12 and 13.

Appendix II.

Method of Calculating the Lump Losses when using a 6 per cent. charge of 1-in. Cubes in Stage (11).

(294) It is convenient first to set down the schedule of heat transmission per foot run of kiln, and afterwards to show that the various assumptions made in it are correct. Preliminary data are given in Table XL. This schedule is representative of the calculation method when the lump losses are taken into account.

The relevant temperatures, together with the corresponding values for black body radiation and for gas radiation, are given below.

	Temperature (deg. Fah.)	B.T.U. per square foot per minute	
		Black body radiation	Gas radiation
(*a*) Flame	2,450	2,070	—
(*b*) Gas	2,133	—	265
(*c*) Lining (upper arc)	2,364	1,836	346
(*d*) Lining (lower arc)	2,186	1,416	—
(*e*) Material (chord)	1,656	579	140
(*f*) Material (lower arc)	1,967	1,002	—

(*g*) The lining storage factor is 0.63

SCHEDULE OF HEAT TRANSMISSION.

At the centre of Stage (11)	B.T.U. per foot run of kiln per minute	
(1) Radiation, flame to upper arc $(2070 - 1836) \times 0.87 \times 0.9 \times 0.9 \times 25.14$	4,135	
(2) Radiation, gas to upper arc $(265 - 346) \times 0.13 \times 0.9 \times 25.14$	−238	
(3) Convection, gas to upper arc $(2133 - 2364) \times \frac{1.11}{60} \times 25.14$	−107	3,790
(4) Radiation, flame to material chord $(2070 - 579) \times 0.87 \times 0.9 \times 0.9 \times 6.38$	6,685	
(5) Radiation, gas to material chord $(265 - 140) \times 0.13 \times 0.9 \times 6.38$	93	
(6) Convection, gas to material chord $(2133 - 1656) \frac{1.21}{60} \times 6.38$	61	6,839
(7) Radiation, upper lining arc to chord $(1836 - 579 - 346 + 140) \times 0.13 \times 0.9 \times 0.9 \times 6.38$		706
(8) Radiation, lower lining arc to material $(1416 - 1002) \times 0.9 \times 0.9 \times 6.90$		2,317
(9) Shell radiation loss		767
Total		10,629

By equating the sum of lines (1), (2), and (3) to the sum of lines (7), (8), and (9) it is seen that the heat supplied to the kiln lining is equal to the heat given out.

(295) INFLUENCE OF LINING STORAGE FACTOR.—It is shown in para. (170), Part VIII, that if the difference between the flame temperature and the average material temperature on the lower arc is denoted by A, and the difference between the average surface temperatures of the upper and lower lining arcs by X, then

$$\text{Lining storage factor} = 1 - \frac{X}{A}$$

In this instance $X = 2{,}364 - 2{,}186 = 178$ deg. F.

$A = 2{,}450 - 1{,}967 = 483$ deg. F.

$$\therefore \text{Lining storage factor} = 1 - \frac{178}{483}, = 1 - 0.37, = 0.63.$$

Hence the lining storage factor and the quantities X and A are in agreement.

(296) LUMP LOSS ON CHORD.—This can conveniently be expressed by a formula, the notation used being as follows:

Let aQ = heat supply on chord (plane surface) per square foot per minute.
bQ = heat supply to one cube face on chord per square foot per heating cycle.
cQ = heat supply to one cube face on chord per square foot per hour.
Td = lump loss on chord.
y = thickness of equivalent block in feet.

It follows from the definition of conductivity that

$$cQ = \frac{K \times Td}{y} \quad \text{or} \quad Td = \frac{cQ \times y}{K} \qquad (17)$$

From lines (4), (5), (6), and (7) of the schedule of heat transmission we have

$$aQ = \frac{7{,}545}{6.38} = 1{,}181.$$

The heating time on chord per cycle from Table XL is 0.199 minute, hence

$$bQ = 1{,}181 \times 0.199 = 235.$$

From Table XLI, line (12), the length of a heating cycle for one cube face is $6 \times 1.28 = 7.68$ minutes, hence

$$cQ = \frac{235 \times 60}{7.68} = 1{,}835$$

and $$Td = \frac{1{,}835 \times 0.0246}{0.80} = 56 \text{ deg. F.}$$

The value of y [see para. (269)] is 0.294 in., or 0.0246 ft. This value of the lump loss on chord is entered in line (12) of Table XLI.

(297) HEATING ON THE LOWER ARC.—Assuming the face JK (see *Fig.* 52) comes on to the kiln lining, the temperature rise in the frustrum JKML is found by Schmidt's method. In this instance the equivalent block is divided into four equal plates so that, using the notation of Appendix I, $x = \frac{0.0246}{4} = 0.00615$ ft. The volume of the equivalent block is greater than that of the frustrum in the ratio of 1 to 0.425, hence the specific heat of the equivalent block is taken at $0.25 \times 0.425 = 0.106$.

By formula (14) the value of t (in seconds) is

$$t = \frac{(0.00615)^2 \times 74 \times 0.106 \times 3,600}{2 \times 0.80} = 0.67$$

The relevant figures for the heating period are entered in Table XLIV.

TABLE XLIV.

STAGE (II), 1-IN. CUBE, CHARGE 6 PER CENT.
HEATING ON LOWER ARC.

Line No.	Period No.	Time (seconds)	Surface temperature (deg. F.)	x	$2x$	$3x$	$4x$
(1)	0	0	56	42	28	14	0
(2)	1	0.67	250	42	28	14	0
(3)	2	1.34	292	139	28	14	0
(4)	3	2.01	327	160	77	14	0
(—)	—	—	—	—	—	—	—
(19)	18	12.06	427	316	209	103	0
(20)	19	12.73	428	318	209	104	0
		(1)	(2)	(3)	(4)	(5)	(6)

(298) Referring to line (1), the temperature of the face LM (see *Fig.* 52) is taken as zero in Col. (6). The lump loss on chord of 56 deg. F. is entered in Col. (2), and the line is completed by assuming a straight line gradient across the block.

Before applying formula (15) the values of gT and H have to be found. From para. (294), line (d), the lining temperature (lower arc) is 2,186 deg. F., deducting 1,600 deg. which in this case is zero, and $gT = 586$ deg. F.

From line (8) in the schedule of heat transmission the heat radiated to the underside of the material in B.T.U. per square foot per minute is $\frac{2,317}{6.90} = 336$. The mean temperature difference [see lines (d) and (f)] is $2,186 - 1,967 = 219$ deg. F. Remembering that H is expressed in hours, it follows that

$$H = \frac{336 \times 60}{219} = 92.$$

Also $x = 0.00615$, so that $Hx = 92 \times 0.00615 = 0.565$.

We also have $K - Hx = 0.235$, and $3K + Hx = 2.965$, hence by formula (15)

$$aT = \frac{(2 \times 586 \times 0.565) + 0.235L + 0.8(M + R)}{2.965}$$

$$\text{or} \quad aT = 223 + \frac{L}{12.6} + \frac{M + R}{3.71}$$

(299) Referring to Table XLIII, the temperatures corresponding to R, S, and V in line (2) are easily found. The surface temperature in line (2), Table XLIV, is $223 + \frac{56}{12.6} + \frac{84}{3.71} = 250$ deg. F. Formula (16) is not required in this instance, since the value of eT in each line is zero. Rather more than 19 periods are required for the heating time of 12.9 seconds on the lower arc.

Table XLIV can now be completed; the first four lines and the last two are here reproduced.

(300) The surface temperatures in Col. (2) are next plotted against the times in Col. (1), and the average value is found to be 367 deg. F. This is the average

lump loss during heating on the lower arc, and it is entered in line (12) of Table XLI. The surface temperature curve is shown in *Fig.* 53.

The initial temperature gradient across the frustrum JKML due to heat received on chord is shown by the line HK in *Fig.* 56. The temperature gradient at the end of the heating period is shown by line (20) of the table and by the curve LK.

The line MNK shows the temperature distribution at the end of the second period. It will be remembered that a temperature of 1,600 deg. F. is taken as zero.

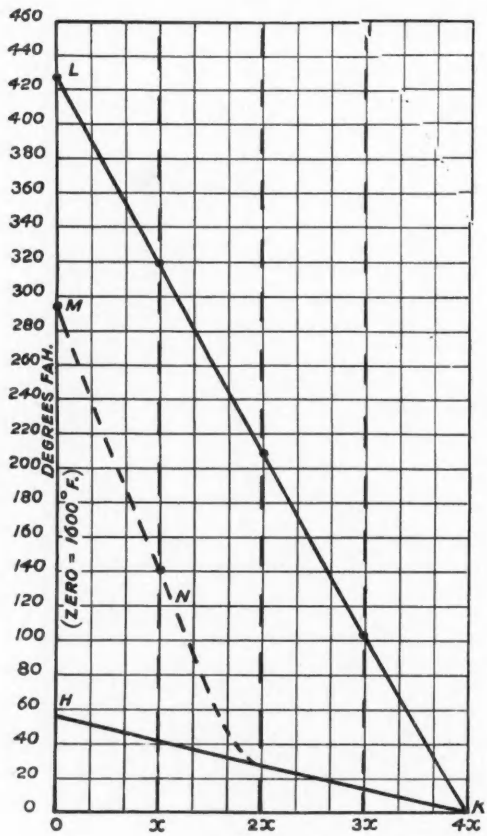

Fig. 56.

The schedule of heat transmission can now be completed, the material temperature on chord being taken at 1,600 + 56 deg. F. and on the lower arc at 1,600 + 367 deg. F. [see lines (e) and (f) in para. (294)].

[Previous articles of this series appeared in *Cement and Cement Manufacture* for December, 1932; March, June, August, October, and December, 1933; January, May, July, and October, 1934; April, 1935; January, 1936.]

Studies on Mixed Portland Cements.

By SHOICHIRO NAGAI, KEIMA MATSUOKA and KENJI NOMI.

THE authors have issued a further report on their investigations on the effect of mixing different Portland cements, and this was presented to the Institute of Silicate Research, Tokyo Imperial University, in September, 1935. The following is an abstract of the Japanese paper.

Two Portland cement clinkers and six admixtures (two kinds of spent shale, one basic blast furnace slag, three kinds of natural siliceous earth containing a large amount of soluble silica) were mixed in the proportions of 60 : 40 or 50 : 50, and ground to make various cement samples (two ordinary Portland cements and 12 mixed Portland cements).

The chemical analyses of these cement samples are given in Table I.

These cement samples were compared for mortar strengths by the following methods, (*a*) Compressive strength tests were made with 7.07 cm. cubical test pieces and tensile strength tests were made with 8-shape test pieces, which were made with mortar of small water-cement-ratio ($w/c \times 100 = 26$ to 32 per cent.), which is the method specified in the Japanese Standard for Portland Cement, and (*b*) Bending and compressive tests were made with 4 cm. by 4 cm. by 16 cm. (or 4 cm. by 4 cm. by 20 cm.) prismatic test pieces made with mortar of large water-cement-ratio (60 to 70 per cent.), which is the proposed new method of Professor Rôs in Switzerland and Dr. Haegermann in Germany.

The test pieces of plastic mortar were tested to compare the expansion or contraction in water-curing for various ages. The results of the measurement of expansion or contraction are given in Table II.

From these results it is seen that mixed Portland cements have the same rates of expansion and contraction as common Portland cement.

These prismatic test pieces were also used for the comparison of the expansion and contraction or disintegration of hardened mortar half immersed in various salt solutions for long ages. The bending and compressive strengths were compared with test pieces cured in water for a period of 56 weeks. The results are given in Table III.

From these results some special features of mixed Portland cements are clearly seen, (1) Reaction to sulphate solution is considerable with common Portland cement, a 10 per cent. Na_2SO_4 solution being more reactive than a 10 per cent. $MgSO_4$ solution ; (2) Mixed Portland cements are more resistant to sulphate and chloride solutions than common Portland cement ; (3) Among chloride solutions, 10 per cent. $MgCl_2$ solution is more reactive than 10 per cent. NaCl solution ; (4) Bending and compressive strengths of mixed Portland cement mortars cured in 10 per cent. NaCl and 10 per cent. Na_2SO_4 solutions exceed the strengths of those cured in water ; (5) Strengths of mixed Portland cements cured in water for 56 weeks are nearly equal to, or a little greater than, those of common Portland cement cured in the same conditions, which shows the large increment of strength of mixed Portland cement with longer curing.

TABLE I.

No. of sample.	Type of cement.	Chemical composition, per cent.								
		Loss on ignition.	Insoluble residue.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Free CaO
85	Common Portland cement	0.34	0.08	20.94	5.53	2.53	67.45	1.14	1.94	1.07
86	Spent Shale mixed P. C.	0.45	34.13	36.65	11.45	5.92	41.64	1.39	2.04	—
87	,, ,, ,, ,,	0.48	42.38	40.01	13.72	6.94	35.07	1.45	1.98	—
90	Keisanhakudo ,, ,,	3.56	41.07	44.46	8.59	2.90	37.04	1.27	1.97	0.49
91	Kayohakudo ,, ,,	2.06	39.82	52.01	5.24	1.14	37.54	0.45	2.18	0.54
92	Yokeihakudo ,, ,,	2.14	41.46	54.78	4.36	1.31	35.81	1.26	1.78	0.58
93	Blast-furnace slag cement	−0.72	0.10	25.57	9.87	2.38	56.21	1.70	1.98	0.60
101	Common Portland cement	0.16	0.08	20.96	5.50	2.33	68.16	1.25	1.37	0.76
102	Yokeihakudo mixed P. C.	1.21	31.82	47.03	5.37	1.41	42.45	0.81	1.27	0.45
103	,, ,, ,, ,,	1.75	39.03	53.94	4.84	1.12	35.84	0.72	1.31	0.33
104	Kayohakudo ,, ,,	1.63	30.69	45.94	5.52	1.43	42.84	0.96	1.33	0.41
105	,, ,, ,, ,,	2.13	38.70	52.62	4.69	1.34	36.80	0.91	1.28	0.36
108	Calcined green shale mixed P. C.	0.74	22.02	32.39	13.26	5.58	43.85	2.72	1.38	—
109	,, ,, ,, ,,	0.91	26.60	35.32	15.28	6.08	37.79	2.05	1.35	—

TABLE II.

No. of sample.	Type of cement.	Expansion (+) or Contraction (−), mm/10m.					
		4 weeks' water-curing to 1 day hardening.	Water-curing to 4 weeks hardening.				
			4 weeks	8 weeks	21 weeks	32 weeks	52 weeks
85	Common Portland cement	+5.4	−3.7	−4.4	−2.2	−2.2	−0.7
86	Spent shale mixed P. C...	+1.9	−1.5	−2.9	−1.5	−1.5	−2.2
87	,, ,, ,, ,, ..	+1.4	−1.4	−2.1	−1.4	−1.4	−1.4
90	Keisanhakudo ,, ,, ..	+2.5	−2.9	−3.7	−1.4	−1.4	−0.7
91	Kayohakudo ,, ,, ..	+4.8	−2.2	−3.6	−2.2	−2.2	−2.9
92	Yokeihakudo ,, ,, ..	+3.3	−2.2	−3.6	−3.6	−2.9	−2.2
93	Blast-furnace slag cement	+2.6	−1.4	−1.4	+0.7	+0.7	+0.7
101	Common Portland cement	+5.6	−2.9	−2.9	−2.9	−2.6	−3.6
102	Yokeihakudo ,, ,, ..	+2.2	−1.4	−2.1	−1.1	−0.7	−2.4
103	,, ,, ,, ..	+1.4	−1.4	−3.1	−2.1	−1.8	−2.9
104	Kayohakudo ,, ,, ..	+2.0	−1.4	−2.5	−0.7	−0.7	−2.8
105	,, ,, ,, ..	+1.4	−2.1	−2.8	−1.4	−1.4	−3.2
108	Calcined green shale mixed P. C.	+2.6	−1.4	−2.8	−1.4	−1.4	−2.9
109	,, ,, ,, ,, ..	+1.9	−1.4	−2.5	−0.4	−0.4	−3.5

TABLE III.

No. of sample.	Type of cement.	Cured in	Expansion (+) or contraction (−), mm/10m.	Total bending load.	Total compressive load. Upper half.	Total compressive load. Lower half.
				kg.	kg.	kg.
85	Common Portland cement	Water	− 0.7	337.0	7,450	8,000
		10% Na_2SO_4	Disintegrated	—	—	—
		10% $MgSO_4$	,,	—	7,140	—
86	Spent shale mixed P. C.	Water	− 2.2	330.9	7,040	7,180
		10% Na_2SO_4	+ 4.4	545.1	8,680	8,790
		10% $MgSO_4$	+ 6.9	316.1	7,890	5,600
87	,, ,, ,, ,,	Water	− 1.4	337.7	6,380	6,420
		10% Na_2SO_4	+ 2.2	526.4	7,780	7,580
		10% $MgSO_4$	Cracked	377.5	6,090	4,440
90	Keisanhakudo mixed P.C.	Water	− 0.7	394.6	7,600	7,690
		10% Na_2SO_4	+ 5.2	448.4	7,470	7,960
		10% $MgSO_4$	Disintegrated	—	6,460	—
91	Kayohakudo ,, ,,	Water	− 2.9	345.4	6,960	7,790
		10% Na_2SO_4	+ 4.3	409.9	7,420	7,870
		10% $MgSO_4$	Disintegrated	—	5,880	—
92	Yokeihakudo mixed P. C.	Water	− 2.2	354.1	4,420	5,280
		10% Na_2SO_4	+ 1.4	471.2	6,680	6,840
		10% $MgSO_4$	Disintegrated	—	4,920	—
93	Blast-furnace slag cement	Water	+ 0.7	352.7	7,450	4,270
		10% Na_2SO_4	Cracked	—	7,340	—
		10% $MgSO_4$	Disintegrated	—	8,520	—
101	Common Portland cement	Water	− 3.6	338.6	8,630	8,480
		10% NaCl	+ 7.1	252.0	8,620	7,220
		10% $MgCl_2$	+ 6.3	245.1	8,130	5,390
		10% Na_2SO_4	Disintegrated	—	—	—
		10% $MgSO_4$	Disintegrated	—	7,500	—
102	Yokeihakudo mixed P.C.	Water	− 2.4	362.5	7,220	7,660
		10% NaCl	+ 2.8	390.1	7,270	6,930
		10% $MgCl_2$	+ 7.0	313.1	7,400	4,150
		10% Na_2SO_4	+11.3	553.0	6,700	7,360
		10% $MgSO_4$	Cracked	251.5	4,760	1,090
103	,, ,, ,,	Water	− 2.9	362.5	7,080	7,300
		10% NaCl	+ 1.1	437.6	7,320	7,140
		10% $MgCl_2$	+ 1.1	344.9	6,880	3,880
		10% Na_2SO_4	+ 2.8	503.5	6,850	7,030
		10% $MgSO_4$	Cracked	168.7	4,660	480
104	Kayohakudo ,, ,,	Water	− 2.8	305.9	7,460	7,460
		10% NaCl	+ 4.3	367.0	7,600	7,310
		10% $MgCl_2$	+ 2.8	338.8	7,610	4,270
		10% Na_2SO_4	+35.7	544.8	7,700	7,150
		10% $MgSO_4$	Cracked	227.1	6,580	1,920
105	,, ,, ,, ,,	Water	− 3.2	322.5	7,400	7,510
		10% NaCl	+ 0.7	499.9	7,140	7,420
		10% $MgCl_2$	+ 2.8	324.1	6,580	3,910
		10% Na_2SO_4	+ 9.2	513.8	7,380	7,000
		10% $MgSO_4$	Cracked	144.5	5,100	1,010
108	Calcined green shale mixed P. C.	Water	− 2.9	246.6	7,210	6,860
		10% Na_2SO_4	+ 9.2	462.2	7,510	7,100
		10% MgSO	Disintegrated	—	4,120	—
109	,, ,, ,, ,,	Water	− 3.5	258.5	7,340	7,540
		10% NaCl	+ 0.7	398.3	7,350	7,460
		10% $MgCl_2$	+ 2.8	387.0	7,110	4,020
		10% Na_2SO_4	+ 5.8	452.2	6,940	6,720
		10% $MgSO_4$	Cracked	206.0	3,600	640

The Corrosion of Portland Cement in Water.

We have received the following from Mr. J. G. Kay, Managing Director of the Lafarge Aluminous Cement Co., Ltd. :—

" SIR,—I have read with interest the paper on ' The Corrosion of Portland Cement in Water ' reported in the December number of your journal.

" The principle of measuring the degree of corrodibility of set cement by means of determinations of the solubility of set cement which has been ground to a powder is liable to be fallacious, and to produce results in complete contradiction with facts, as demonstrated in innumerable practical works. The fallacy is easily explained. When making a pat of neat cement, even if it is cured under water, the individual grains of set cement are seldom, if ever, all completely hydrated. When such a pat is ground to powder, a high proportion of these incompletely hydrated grains are fractured, and the unhydrated cement contained therein thereby exposed. Lixiviation cannot, therefore, determine the solubility of set cement, but determines the solubility of cement some of which is set and some of which is unhydrated. The results inevitably show a relatively high degree of solubility, but it is quite erroneous to describe this solubility as being the solubility of set cement.

" The mechanism I have described can readily be seen in the microscope, but a simple way of demonstrating the truth of my statement is to take a briquette of neat cement, say, one month old, and grind the cement to a powder of the same fineness as the original cement. Then gauge this powder with water in exactly the same way as if it were fresh cement, making once more a tensile briquette with the paste. At the age of one month the new briquette will be found to possess a very considerable proportion of the strength of the original briquette, thus demonstrating that a high proportion of the original cement had not been completely hydrated.

" Rengade, writing in ' Revue des Matériaux de Construction et de Travaux Publics,' was, I think, the first to draw attention to this fallacy, when investigating the relative solubility in distilled water of Portland cement and high-alumina cement. The method described in the paper referred to had shown that, if anything, the high-alumina cement was more soluble than the Portland cement, whereas from exhaustive experiments which he had carried out on unfractured surfaces it had been shown that the high-alumina cement was enormously less soluble than any other type of cement made, thus proving the fallacy of the method as described by the authors of the paper."

Data Relating to Fan Horse-Power.

THE theoretical horse-power necessary to pass V cu. ft. of gas per minute through a fan against a pressure P lb. per square foot is given by the formula

$$\text{H.P.} = \frac{V \times P}{33{,}000}$$

Since pressures are usually measured by a water gauge,

$$P = \frac{62.4}{12} \ (= 5.2) \times \text{inches water gauge.}$$

In order to obtain the value of P it is necessary to take the difference in pressure at the inlet and outlet sides of the fan and as close to it as possible. If a fan is withdrawing gas from a rotary kiln and discharging into a chimney there will be a negative pressure (suction) on the inlet side of the fan while the pressure on the outlet side may be positive, negative, or nil with reference to atmosphere. The pressure at the outlet side is dependent upon the relative cross-sectional areas of the chimney and the discharge pipe attached to the fan, in addition to the natural draught of the chimney. Thus, if the suction on the inlet side of the fan is 4 in. water gauge and on the outlet side there is a pressure of 0.5 in. water gauge above atmospheric pressure, the actual pressure within the fan casing is 4.5 in. water gauge.

To ascertain the horse-power required to be supplied to the fan, its efficiency must be known. In the following calculations the fan efficiency is taken to be 65 per cent.

From the formula, the practical horse-power required to enable a properly-proportioned fan to pass V cu. ft. of gas per minute against a pressure of H inches water gauge would be

$$\frac{V \times 5.2 \times H \times 100}{33{,}000 \times 65} = 0.0002424 \times V \times H$$

EXAMPLE.—A fan passes 50,000 cu. ft. of gas per minute at a suction of 2 in. water gauge on the inlet side of the fan and a pressure of 0.5 in. water gauge on the outlet side. What horse-power will be required, assuming a fan efficiency of 65 per cent. ?

The actual pressure within the fan casing is 2 in. suction and 0.5 in. pressure, giving a total of -2.5 in. water gauge with respect to atmosphere.

Then, H.P. $= 0.0002424 \times 50{,}000 \times 2.5 = 30.3$.

Effect of Alterations in Temperature.

The relation between volume, weight, pressure, and power for a fan working with gas at different temperatures is given in Table I. In this table the volumes, weights, pressures, and power at temperatures from 450 to 750 deg. F. are expressed as factors of unit quantities at 450 deg. F. The basis upon which the various factors have been calculated is as follows.

Col. 2.—The volume of a fixed weight of gas is directly proportional to its absolute temperature.

Col. 3.—The weight of a fixed volume of gas is inversely proportional to its absolute temperature.

Col. 4.—The pressure difference when the fan handles a fixed volume of gas is inversely proportional to its absolute temperature.

Col. 5.—The pressure difference when the fan handles a fixed weight of gas is directly proportional to the square of the speed and inversely proportional to the absolute temperature of the gas.

Col. 6.—The power required when the fan handles a fixed volume of gas is inversely proportional to its absolute temperature.

Col. 7.—The power required when the fan handles a fixed weight of gas is directly proportional to the cube of the speed and inversely proportional to the absolute temperature of the gas.

Col. 8.—The power required to maintain a fixed pressure difference is directly proportional to the square root of the absolute temperature of the gas.

TABLE I.

Temp. deg. Fahr. 1	Volume of fixed weight. 2	Weight of fixed volume. 3	Pressure difference for fixed volume. 4	Pressure difference for fixed weight. 5	Power for fixed volume. 6	Power for fixed weight. 7	Power for fixed pressure difference. 8
450	1.00	1.00	1.00	1.00	1.00	1.00	1.00
475	1.03	0.97	0.97	1.03	0.97	1.05	1.01
500	1.05	0.95	0.95	1.05	0.95	1.11	1.02
525	1.08	0.93	0.93	1.08	0.93	1.17	1.04
550	1.11	0.90	0.90	1.11	0.90	1.23	1.05
575	1.14	0.88	0.88	1.14	0.88	1.29	1.07
600	1.16	0.86	0.86	1.16	0.86	1.35	1.08
625	1.19	0.84	0.84	1.19	0.84	1.42	1.09
650	1.22	0.82	0.82	1.22	0.82	1.49	1.10
675	1.25	0.80	0.80	1.25	0.80	1.56	1.12
700	1.28	0.78	0.78	1.28	0.78	1.63	1.13
725	1.30	0.77	0.77	1.30	0.77	1.70	1.14
750	1.33	0.75	0.75	1.33	0.75	1.77	1.15

EXAMPLE.—A fan handles 50,000 cu. ft. of gas per minute against a pressure of 4 in. water gauge at a temperature of 700 deg. F. with the expenditure of 48 h.p. If the gas be cooled to 500 deg. F., what would be

(1) The power necessary to maintain the pressure at 4 in. water gauge ?

(1*a*) The alteration in volume and weight of gas passing the fan per minute, assuming the gas density at 700 deg. F. to be 0.032 lb. per cu. ft., and the pressure maintained at 4 in. water gauge ?

(2) The power necessary to handle the same volume of gas at 500 deg. F. ?

(2*a*) The alteration in suction head and weight of gas if the fan is run at the same speed at 700 and 500 deg. F. ?

(1).—From col. 8 the ratio of the power at 500 deg. F. to the power at 700 deg. F. when the pressure remains constant is 1.02 : 1.13. Thus the horse-power necessary at 500 deg. F. will be $48 \times \frac{1.02}{1.13} = 43.3$.

(1*a*).—At equal pressures, the volume of gas passing through the fan per minute is directly proportional to the power required. The volume of gas per minute at 500 deg. F. will be $50{,}000 \times \frac{43.3}{48.0} = 45{,}110$ cu. ft. The weight of gas passing through the fan at 700 deg. F. is $50{,}000 \times 0.032 = 1{,}600$ lb. From col. 3 the ratio of the gas densities at 500 and 700 deg. F. is 0.95 : 0.78. Thus the weight of gas passing through the fan at 500 deg. F. is

$$45{,}110 \times 0.032 \times \frac{0.95}{0.78} = 1{,}758 \text{ lb.}$$

(2) From col. 6 the ratio of the power at 500 deg. F. to the power at 700 deg. F., when the volume remains constant, is 0.95 : 0.78. Thus the horse-power necessary at 500 deg. F. will be $48 \times \frac{0.95}{0.78} = 58.45$.

(2*a*).—From col. 4 the ratio of the pressure differences at 500 and 700 deg. F. and constant fan speed, i.e. when the volume of gas passed by the fan remains constant, is 0.95 : 0.78. Thus the pressure difference at 500 deg. F. will be $4 \times \frac{0.95}{0.78} = 4.87$ in. water gauge. As shown in (1*a*) the weight of gas handled by the fan at 700 deg. F. is 1,600 lb. From col. 3 the ratio of the weights of gases at 500 and 700 deg. F. is 0.95 : 0.78 when the volume remains constant. Thus the weight of gas passing through the fan at 500 deg. F. is

$$1{,}600 \times \frac{0.95}{0.78} = 1{,}950 \text{ lb.}$$

Effect of the Density of the Gas on the Power Required.

When it is required to know the power taken by a fan when passing a definite weight of gas per minute, it is necessary to know the gas density at the inlet to the fan. The practical horse-power (assuming a fan efficiency of 65 per cent.) is then given by the formula

$$\text{H.P.} = \frac{W \times 5.2 \times H \times 100}{33{,}000 \times D_t \times 65}$$

where W = weight of gas per minute.
H = inches water gauge pressure (or suction).
D_t = gas density in lb. per cubic foot at temperature t deg. F. at inlet to fan.

If $W = 100$ and $H = 1.0$ in. water gauge, then $\text{H.P.} = \frac{0.02424}{D_t}$

Table II gives the fan horse-power required to pass 100 lb. of gas per minute against a pressure of 1 in. water gauge for gas densities from 0.030 to 0.0449 lb. per cubic foot.

EXAMPLE.—A fan is required to pass 2,000 lb. of gas per minute at a pressure difference of 3 in. water gauge. What power would be required, the gas density at the inlet to the fan being 0.0343 lb. per cubic foot and the fan efficiency 65 per cent.?

From Table II, the power required per 100 lb. gas at 1 in. water gauge and gas density of 0.0343 is 0.706 horse-power hour. Thus for 2,000 lb. of gas at 3 in. water gauge the power required will be

$$\frac{0.706 \times 2{,}000 \times 3}{100} = 42.36 \text{ h.p.h.}$$

TABLE II.

FAN HORSE-POWER IN H.P.H. PER 100 LB. KILN GASES PER MINUTE AT VARIOUS GAS DENSITIES AGAINST A PRESSURE OF 1 IN. WATER GAUGE. (FAN EFFICIENCY 65 PER CENT.)

Gas density in lb. per cu. ft.	0	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009
0.030	0.808	0.805	0.802	0.800	0.798	0.795	0.792	0.790	0.787	0.784
0.031	0.782	0.779	0.777	0.774	0.772	0.770	0.767	0.764	0.762	0.760
0.032	0.758	0.755	0.752	0.750	0.748	0.746	0.744	0.741	0.739	0.737
0.033	0.734	0.732	0.730	0.728	0.726	0.724	0.722	0.719	0.717	0.715
0.034	0.713	0.710	0.708	0.706	0.704	0.702	0.701	0.699	0.696	0.694
0.035	0.692	0.690	0.689	0.687	0.685	0.683	0.681	0.679	0.677	0.675
0.036	0.674	0.672	0.670	0.668	0.666	0.664	0.662	0.660	0.659	0.657
0.037	0.656	0.654	0.652	0.650	0.648	0.646	0.644	0.643	0.642	0.640
0.038	0.638	0.636	0.634	0.633	0.632	0.630	0.628	0.626	0.625	0.624
0.039	0.622	0.620	0.618	0.617	0.615	0.614	0.612	0.610	0.609	0.608
0.040	0.606	0.604	0.602	0.601	0.599	0.598	0.596	0.595	0.594	0.593
0.041	0.591	0.589	0.588	0.586	0.585	0.584	0.582	0.581	0.580	0.579
0.042	0.578	0.576	0.575	0.573	0.572	0.570	0.569	0.567	0.566	0.565
0.043	0.564	0.562	0.561	0.560	0.559	0.558	0.556	0.555	0.553	0.552
0.044	0.551	0.549	0.548	0.547	0.546	0.545	0.543	0.542	0.541	0.540

Air Separation.

The following is an abstract of a paper by MR. Raymond Wilson (of the American Portland Cement Association) which appeared in a recent number of " Rock Products."

Discussions relative to methods of calculating the efficiency of classifiers have been published. Catlin[1] gives a formula which is in common use in the cement industry. By this formula, the efficiency of the separator is the ratio of fine material recovered in the fine product to the total fine material fed. Newton[2] gives a formula generally used in metallurgy, which is in effect that given by Catlin with added factors which penalise the separator for recovery of oversize in the fine product. In cement clinker grinding both formulæ would generally be applied to 200-mesh fineness, though any desired size can be considered as marking the dividing line between fine and coarse material.

These formulæ are very useful in the day-to-day use of a separator. For some purposes they give all the information that is needed, but they give a very incomplete picture of the nature of the separation. The weakness of both formulæ is that they encourage the assumption that separation and recovery in the fine product are equally complete throughout the range of sizes designated as fine material. These formulæ must be applied to a specific particle size. When the separator is operating on cement clinker, efficiency formulæ give misleading indications of mill and separator performance, due to the fact that the quantity of coarse material present is not an adequate measure of the properties resulting from grinding. On the whole, reliance on the common efficiency formulæ has complicated studies of the use of separators in grinding and has doubtless retarded the improvement of separator design.

Attempts have been made to apply the relations between particle size and settling rate to studies of separator performance.[3,4] These relations are of great importance in connection with test elutriators where the separation is made under conditions of straight-line air flow and continued until the residue retains practically no fine material. In commercial separators of the types considered here, neither of these conditions holds ; the rising air current has a motion which is turbulent and cyclonic and the feed falls through the air stream with only a brief period of contact. The first condition causes coarse particles to carry over to the fine product, while the second brings about retention of fine material in the coarse product.

It is apparently a hopelessly complicated task to account for turbulence, centrifugal forces and incomplete separation by theoretical studies or the use of general laws. Nevertheless, any machine has certain inherent characteristics which can be experimentally determined. Furthermore, if these characteristics are properly defined, they will show some kind of regular variation with changes in operating conditions.

Method of Rating Performance.

It is the author's purpose to present an improved method of describing air separator performance which defines the separation characteristics throughout

the whole range of particle sizes affected. It can best be understood from a sample calculation.

Fineness data from a test on a separator are given in *Table* 1. Fineness determinations include air elutriation[5] and sieve tests on the feed to and the tailings and fines from the separator. These fineness data are used first to calculate the distribution of the feed between the fine and the coarse product. The quantity of fine product is given in the last column, the formula for the calculation being given at the head of the column. The formula is applied to fineness at various sizes. The average of the values marked with an asterisk is used for subsequent calculations.

Clinker is fed to the separator at the rate of 150 barrels per hour. The fineness data in *Table* 1 indicate that the fine product is 46 per cent. of the feed, or 69 barrels per hour ; the tailings then amount to 81 barrels per hour. When these quantities are known it becomes possible to convert the fineness data to show the number of barrels per hour in each individual size range in each of the material streams. These converted data are given in *Table* 2 and shown graphically by the distribution curves in the upper part of *Fig.* 1.

TABLE 1.

Size.	Cumulative percentage finer than size shown.			Per cent. of feed to fine product. $\left(\frac{a-b}{c-b} \times 100\right)$
	Feed (a)	Tails (b)	Fines (c)	
10 microns	9.6	3.1	16.0	50
20 microns	18.0	5.0	32.6	47*
30 microns	27.5	7.0	52.0	46*
45 microns	34.2	8.0	64.2	47*
200-mesh	45.6	13.9	86.8	44*
100-mesh	59.9	29.1	98.4	44*
48-mesh	74.4	56.7	99.9	41
28-mesh	87.6	80.9	100.0	35
14-mesh	97.1	95.2	—	—
8-mesh	99.8	99.8	—	*Av. 46

Feed rate : 150 barrels per hour.
Tailings : $150 \times 0.54 = 81$ barrels per hour.
Fines : $150 \times 0.46 = 69$ barrels per hour.

In *Fig.* 1 the quantity of material in a given size-range is plotted against the average particle size in that range, and the plotted points for each material are connected by curves. The size scale is an arbitrary one in which the air analyses and sieve separation points are spaced at equal intervals and the mid-point of each interval is taken as the average size. While appearing somewhat artificial, this method of plotting these data is a convenient means of visualising the concentration of material in various sizes.

Distribution curves, plotted on the barrels per hour basis as in the upper part of *Fig.* 1, show the separation quantitatively over the whole size-range. They show that the fine product receives most of the 0–45 micron material,

while the material coarser than 48-mesh is completely recovered in the tailings. In the zone between 45 microns and 48-mesh the separation is less positive than in the regions on either side.

The separation may be regarded as a process in which a mixture of various components is treated. Each component reacts to the treatment in its characteristic manner and is recovered in the finished product in quantity dependent on its nature and the nature of the treatment. The components are the various sieve and air analyser fractions comprising the feed. The yield of each component in the fine product of the separator may be expressed as the percentage ratio which it bears to the maximum possible yield of that particular size. This is

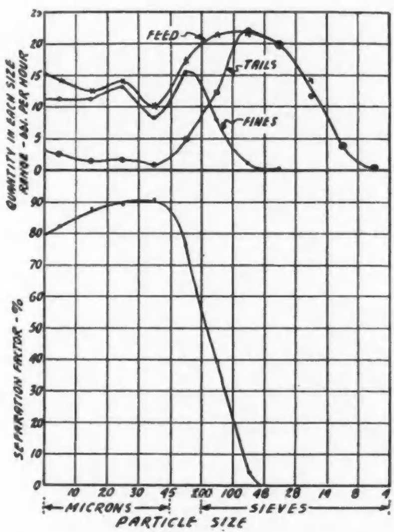

Fig. 1.—Separation diagram and corresponding separator performance curve.

calculated from the data in *Table* 2 by dividing the quantity in a given size-range in the fine product by the total quantity in that size-range in the fine and coarse products combined. In this paper, the per cent. recovery of each individual fraction in the fine product is referred to as the " separation factor " for that size-range. The separation factors for the various size-ranges are given in the last column of *Table* 2.

The separation factor for each size indicates the distribution of material of that size between the fine and the coarse product. The relations among the separation factors for different sizes of particles define the characteristics of the separator for the particular conditions of the test. These relations are more clearly shown if the separation factor is plotted against particle size as shown

TABLE 2.

Size-range.	Quantity in size range barrels per hour.			Separation factor.	
	Feed (a)	Tails (b)	Fines (c)	Totals ($b + c$)	$\left(\frac{c}{b+c} \times 100\right)$
Total	150	81	69	150	—
0–10 microns ..	14.4	2.5	11.0	13.5	82
10–20 microns ..	12.6	1.5	11.4	12.9	88
20–30 microns ..	14.3	1.6	13.4	15.0	90
30–45 microns ..	10.0	0.8	8.4	9.2	91
45 mic.–200 mesh	17.6	4.8	15.6	20.4	76
200–100 mesh ..	21.5	12.3	8.0	20.3	39
100–48 mesh ..	21.8	22.4	1.0	23.4	4
48–28 mesh ..	19.8	19.6	0.1	19.7	0
28–14 mesh ..	14.3	11.6	0	11.6	0
+ 14 mesh ..	4.3	3.9	0	3.9	0

in the lower part of *Fig.* 1. The curve connecting the plotted points shows that there is a continuous variation in per cent. yield with particle size, relatively high for the 0–10 micron range, increasing somewhat over the 10–45 micron range, and decreasing sharply in the range coarser than 45 microns. Efficient recovery of fines is denoted by high values for points defining the left-hand portion of the curve, while a steep slope of the right-hand portion indicates selectiveness or close separation.

Any separation on the basis of particle size can be described by curves of the general type shown in the upper and lower parts of *Fig.* 1. The upper diagram gives more information, indicating the quantity and grading of the feed and products. The curve of the lower diagram lends itself more readily to comparisons of performance of various separators or of the same separator.

Operating Conditions and Design.

The shape and position of the performance curve depend on the design of the machine and on the operating conditions. The effects of varying a number of the operating conditions have been experimentally determined. For the sake of brevity they are shown in *Fig.* 2 by a series of performance curves, without including the complete fineness data on which they are based.

The fineness of the feed has some effect on the performance of the separator. From the results of several tests it appears that larger percentage yields of each size are obtained from a coarse feed than from a fine feed. The curves in diagram *A* of *Fig.* 2 are typical of the effect of feed fineness, the feed rate and separator setting being closely similar in both cases. From these curves it appears that variations in feed fineness will result in similar but smaller variations in product fineness.

Apparently the performance of the separator is affected to a slight degree by fairly wide variations in feed rate, and is therefore not illustrated in the diagram. This observation may not apply to very high or very low feed rates.

One method of causing a separator to produce a finer or coarser product is to adjust the rate of air circulation. This may be done by changing the fan speed, opening or closing the main control valves, or by other means. The effects of fan speed and of adjustment of main valves are illustrated in diagrams *B* and *C* of *Fig.* 2. A decrease in the rate of air circulation causes the performance

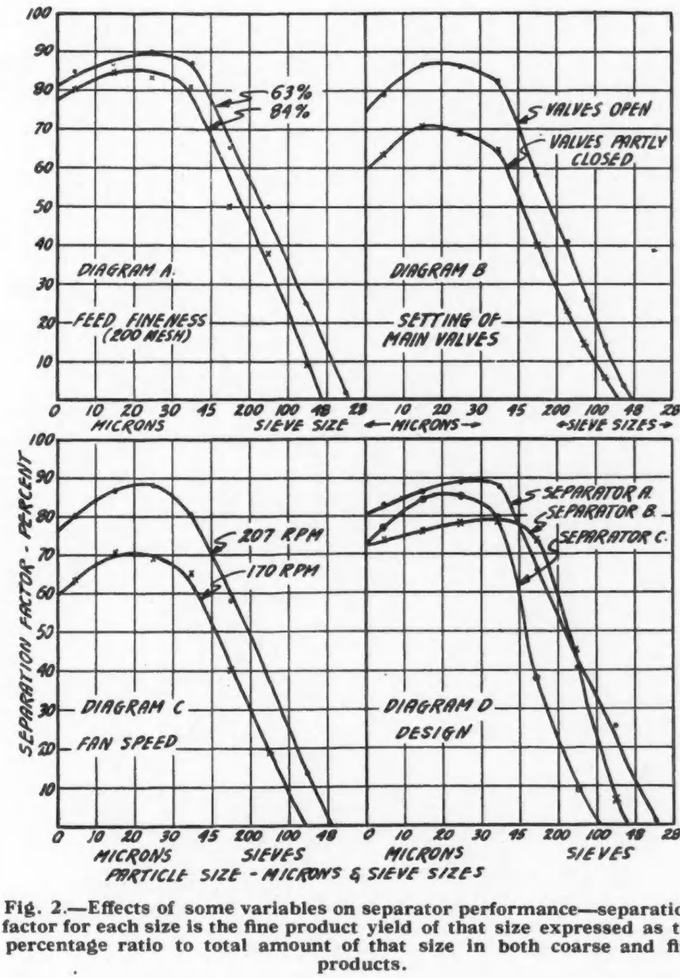

Fig. 2.—Effects of some variables on separator performance—separation factor for each size is the fine product yield of that size expressed as the percentage ratio to total amount of that size in both coarse and fine products.

curve to assume a lower position, without particular change in shape. The decreases in the separation factors are about equal over the whole size-range. Smaller quantities of coarse material are carried over into the fine product, but

only at the expense of decreased recovery of fine material, and hence increased retention of fine material in the tailings. These tests did not include measurements of air velocities in the separator. The observed variations in performance cannot therefore be referred directly to rate of air circulation.

Performance curves for separators made by three different manufacturers are given in diagram *D* of *Fig.* 2. It is not possible to deduce from these tests what details of design and construction are responsible for the differences in performance among these machines. Separator *A* is less selective than the other two, and separator *B*, while about as selective as separator *C*, makes its separation at a larger size. Recovery of fine material by these three machines is somewhat different but, as indicated, could probably be brought to about the same point by control of air circulation without particularly affecting the selectiveness.

There is reason to believe that selectiveness can be improved by placing beater blades on the shaft in the inner chamber of the separator above the distributor plate. The theory of these blades is that oversize particles, lifted by turbulence in the air stream, impinge on the blades and are thrown out of the rising air stream. The machine having the most selective separation, as shown in the diagrams, has these beater blades. By improved selectiveness the yield of fine material has been maintained at a fairly high point, while carry-over of coarse material has been decreased. The result is a greater fineness in the fine product without a corresponding retention of fines in the tailings.

Summarising the foregoing discussion, it appears that adjustments involving only changes in rate of air circulation bring about changes in the separation which may be represented by variations upward or downward in the position of the performance curve. Changes represented by variations in the shape of the curve appear to depend on the design of the separator. Selectiveness is largely a built-in characteristic, while completeness of recovery of fines is dependent on adjustment of air circulation rates also.

Uses of Performance Curve.

Once the characteristics of a separator have been determined the methods and principles set forth above provide a guide to means which are most likely to accomplish any desired change. With a known performance curve the effects of a change in feed fineness can be estimated. By reversing the calculations shown in *Table* 2, and adjusting the values of separation factors in the directions indicated in *Fig.* 2, fineness and yield of the products can be calculated. These calculations are not precise predictions of results under new conditions, but give better indications than could be obtained from the earlier efficiency formulæ. This type of calculation can be applied where a feed stream of fairly constant fineness is to be classified.

Where tailings are returned to the mill which discharges to the separator, the separator performance affects the amount of circulating load and hence the fineness of the mill discharge. In the final analysis, however, it is the mill performance which determines the fineness of the product. Because mill performance is seldom known with the required precision, the methods described

cannot ordinarily be adapted to the advance calculation of quantities which will be carried as circulating loads in closed-circuit grinding. The methods of analysis here developed show how to avoid recirculation of excessive amounts of material already fine enough.

One consistent characteristic of air separators, as reflected in all the tests, is the tendency for recovery of 0–10 micron material to be less complete than the recovery of the sizes between 10 and 30 or 45 microns. Test separations of mill products ground in open circuit are likely to result in separator fine products deficient in fine flour. In closed-circuit operation, however, the separator tailings and therefore the mill product will contain a corresponding excess of this fine flour and the separator product will have about the same grading in the range below 45 microns as the product of open circuit operation of the mill.

It has generally been observed that a higher 200-mesh fineness is necessary in a closed-circuit product than in an open-circuit product of the same clinker. The analysis of separator performance given is complete explanation of this observation. The grading in the finer sizes is the result of action of the mill on the clinker and has not been affected materially by the separation. On the other hand, the grading in the coarser sizes is determined by the separator rather than by the mill. In general, a separator product will contain less material coarser than 200 mesh than a mill product having the same content of fines.

Situation Vacant

WANTED.
Works Manager for large cement works in England. Must have had extensive experience in cement works management generally and with calcinator in particular. Write in confidence, stating experience, salary required, etc., to Box 1315, "Cement and Cement Manufacture," 20, Dartmouth Street, Westminster, S.W.1.

This means that the 200-mesh fineness is not an adequate basis for comparing open and closed-circuit grinding of cement clinker. The more selective the separator, the more unreliable a separation on that basis.

Where a very fine product is desired studies of separator performance by this method might include data on fineness at 60 microns ; inclusion of these data would define more precisely the separation at a point of considerable interest in the production of cements finer than standard.

The air elutriator used in these tests is capable of giving results of a high degree of consistency among themselves. However, few laboratories are equipped with air elutriators having the requisite precision for making tests of this kind. The recently developed Wagner turbidimeter could probably be adapted to provide comparable information on separator performance.

REFERENCES.

[1] Formulæ applicable to air separation. A. W. Catlin, "Rock Products," 34, No. 25 46-8 (December 5, 1931).

[2] A study of classification calculations. Harry W. Newton and William H. Newton. "Rock Products," 35, No. 16, 26-30 (August 13, 1932).

[3] Air separation methods used in fine grinding of rock products. Edmund Shaw. "Rock Products," 30, No. 21, 59-61 (Oct. 15, 1927).

[4] Classifying materials by air separation. E. C. Blanc. "Concrete" (Mill Section) 33, No. 5, 99-103, No. 6, 98-102 (Nov., Dec., 1928).

[5] Air elutriation fineness results given in this paper were obtained on an instrument of the Pearson type. Its calibration by microscopic methods is in close agreement with Stokes' law. Stack velocities in cm. per sec. are $0.0094d^2$, "d" being the particle size in microns. Sieve tests were made with sieves of the Tyler standard screen scale series.

INDEX TO ADVERTISERS.